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Technology Adoption and Schooling:
Amplifier Income Effects of Policies Across Countries

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Abstract

Neoclassical growth models require large productivity/distortion differences across countries to produce the observed disparities in the wealth of nations. In this paper I develop an otherwise very standard neoclassical model with technology adoption and schooling decisions, and show that in this environment the required productivity/distortion differences are much smaller. The schooling and technology adoption features of the model amplify the effects of productivity/distortion differences on income disparity. In particular, for a reasonable parameterization, the model generates 3 times more income disparity than a standard model. Moreover, I find that it is the interaction between the technology adoption and schooling features of the model, and not each in isolation, that accounts for most of the amplifier effect. I show that the model is consistent with the observed patterns of the schooling differences across countries. Standard neoclassical models with schooling have the implication that schooling levels are constant across economies, since wage differences affect in the same proportion the marginal benefit and the opportunity cost of schooling. In my model, average levels of schooling do vary across economies since education is more useful in modern technologies and rich economies use these technologies more intensively.

1 Introduction

A central issue in economics is why the typical worker in the richest 5% of the countries earns twenty-five times more than the typical worker in the poorest 5% of the countries.\footnote{Data sources for this paper are: Summers and Heston (1991), Barro and Lee (1993), Hall and Jones (1998), and Restuccia and Urrutia (1996). The sample of countries is restricted to all 1985 Benchmark countries from Summers and Heston (data is actually collected for these countries) for which there is also schooling data available from Barro and Lee. The result is a cross-section sample of 47 countries for 1985.} Neoclassical growth models require large differences across countries in total factor productivity or inter-temporal distortion policies to produce the observed disparities in the wealth of nations. More precisely, using a capital income share of 1/3 these models require factor differences in productivity/distortion variables of 8 or more. Evidence suggests these required differences are too large. For example, Hall and Jones (1998) find factor differences in a measure of total factor productivity of less than 6, and Restuccia and Urrutia (1996) find factor differences in the relative price of investment goods (a measure of distortions) of 4.

One approach to reconcile the predictions of the neoclassical growth model and the data is to consider broader measures of capital. Mankiw, Romer, and Weil (1992), Parente and Prescott (1994), Chari, Kehoe, and McGrattan (1997), and Restuccia and Urrutia (1996) follow this approach. With a capital income share of around 2/3 and plausible policy distortions, the predictions of these models are very similar to the data in terms of income disparities. However, these models imply very high unmeasured investments, and require similar policy distortions affecting capital accumulation for the broad measure of capital. Another approach is to consider additional features of the model that can amplify the effects of policies to capital accumulation on income disparity. I follow this approach and introduce technology adoption and schooling decisions into an otherwise standard neoclassical growth model. Parente, Rogerson, and Wright (1997) study the implications of introducing home-production to the neoclassical growth model and find substantial amplification effects.

I develop a quantitative dynamic general equilibrium model with schooling and technology adoption decisions. A key feature of this environment is the interaction between these decisions, property that is supported by the evidence. I show that when such features are incorporated, the productivity/distortion differences needed to produce the observed disparities in the wealth of nations are much smaller. The schooling and technology adoption features of the model amplify the effect of the productivity/distortion differences on income disparity. In particular, for a reasonable parameterization, I find that my model generates 3 times more income disparity than a standard model. Moreover, it is the interaction between the schooling and technology adoption features, as opposed to each in isolation, what accounts for most of this amplifier effect.

I develop an environment with dynastic overlapping generations, in which agents live for two periods. In the first period of life, a fraction of the endowment of time can be dedicated to school and the remaining to work. In the second period, the entire endowment of time is dedicated to work. There are two technologies to produce the output-good: Traditional and Modern. A key distinction is that the traditional technology does not require physical and schooling capital services as inputs. Under this assumption, agents working with the traditional technology have no incentive to invest in education. This is the sense in which
the adoption of the modern technology and education are related in the model. There is a schooling technology that requires time, expenditures in education, and parent's schooling capital to produce child's schooling capital.

A continuum of stationary equilibrium for each productivity/distortion level is possible in this environment. In a stationary equilibrium time spent in school is independent of productivity/distortion levels, as in Lucas (1988); and there is a constant fraction of old agents working in the traditional technology with no schooling. Economies with a low productivity/distortion level have in general a low fraction of agents working in the traditional sector, a large fraction of agents going to schools of higher quality, and a high physical capital stock.

The results of the model are broadly consistent with the cross-section pattern of the schooling differences across countries. In the model, rich economies have very low no schooling populations, while poor economies have very high no schooling populations, as it is in the data. Standard neoclassical models with schooling have the implication that schooling levels are constant across economies, since wage differences affect in the same proportion the marginal benefit and the opportunity cost of schooling. In my model, average levels of schooling do vary systematically across economies because education is more useful in modern technologies and rich economies use these technologies more intensively.

Some additional results are the following. First, if some fraction of the traditional output is not measured in national accounts, as is typically the case in very poor countries, income disparity and the "amplifier effect" can be substantially higher. Second, I analyze the effect of a subsidy policy to education. The objective is typically to increase the average years of schooling of the population in order to achieve higher levels of income. In the context of my model, agents in poor economies invest less in education for the same reasons that they invest less in physical capital, since there are lower incentives to accumulate capital. Even though a subsidy to education reduces the fraction of agents with no schooling, and therefore increases the average years of schooling, total income is still substantially lower to the income that could be achieved under an alternative policy of eliminating distortions. For poor economies, subsidies to education do not restore the negative incentives that bad policies have on capital investments.

The paper is organized as follows. Section 2 presents some relevant observations about schooling, technology adoption, and income. Section 3 describes the model economy, and defines equilibrium. Section 4 characterizes a stationary equilibrium for this environment. Section 5 consist of a discussion of the schooling technology and the parameterization of the model. Section 6 describes the results. In the last section I summarize.

2 Some Observations

The following observations motivate the features of the model I develop in the next section.

- **Observation 1:** Average years of schooling and a labor-augmenting measure of productivity are positively correlated with income levels across countries.

The positive correlation between average years of schooling and income levels has been widely documented in the empirical literature, for example Barro and Sala-i-Martin (1995). The positive correlation between a labor-augmenting measure of productivity and income
levels is reported in Hall and Jones (1998) among others. There is a related literature on
the role of technology adoption on development. Jovanovic (1996) argues that adoption
of new technologies absorbs between 20 and 30 times more resources than invention of
technologies. Parente and Prescott (1994, 1997) construct models in which the adoption of
newer technologies and barriers to these adoptions (in the form of monopoly rights) are key
for development. I take this evidence as indicating that schooling and technology adoption
are potentially important features of a model to consider.

• Observation 2: There is an important interaction between the schooling decision of
agents and the adoption of modern technologies by firms.

There is microeconomic evidence supporting the intuitive view that educated workers
are more likely to adopt more advanced technologies, for example Bartel and Lichtenberg
(1987). There is also micro evidence that the incentives to invest in education are higher
in environments where more advanced technologies are being adopted and used. Education
has an individual low value in more traditional environments and a high individual value in
changing environments where modern technologies are being adopted. Schultz (1975, 1980)
and Welch (1970) are examples of this evidence (see also the discussion in Schmitz (1993)).
Welch (1970) argues that skill-biased technical change explains the increase in the demand
for skilled labor that have prevented the decline in the returns to schooling in the presence
of large increases in the education levels of the workforce. The observation that skill-biased
technical change increases the demand for skilled labor is evidence of the relationship between
technology and education. The increase of the demand for skilled labor must be associated
with higher incentives for individuals to invest in education.

Additionally, Dunne and Schmitz (1995) and Doms, Dunne, and Troske (1997) use
plant level data from the Survey of Manufacturing Technology, to study the relationship
between the level of technology and education, workforce composition, and wage differentials.
Dunne and Schmitz find that plants that use more advanced production techniques hire a
higher fraction of skilled workers and pay higher wages. They find support to the view
that technical progress is skill-biased. Doms, Dunne, and Troske study the cross-section
differences in technology across plants and the nature of technology adoptions within plants.
In the cross-section, they show that plants that use newer technologies employ more educated
workforces and pay higher wages. The analysis of adoption of new technologies within plants
shows little correlation between technology use and the skill level of labor. They do find
that plants that adopt new technologies have more educated workforces both pre and post
adoption, which indicates that plants with a more skilled workforce are more likely to adopt
new technologies. The cross-section evidence does indicate that major changes in technology
use must be associated with changes in the composition of skilled labor within plants.

There is also evidence at the more aggregate cross-country level. Figure 1 reports
that there is a positive correlation between an aggregate labor-augmenting measure of pro-
ductivity (Hall and Jones, 1998) and average years of schooling across countries, indicating
that countries with higher levels of schooling, also have higher levels of technology (and/or
technologies are used more efficiently). Nelson and Phelps (1966) and Benhabib and Spiegel
(1994) provide theoretical and empirical support for the view that educated workers have an
advantage at implementing more advanced technologies in a cross-section of countries.
• Observation 3: Differences in average years of schooling between rich and poor countries are accounted for the most part by differences in the distribution of the population across schooling groups.

Table 1 presents information on the distribution of the adult population (25 and over) across schooling and no schooling groups for different sets of countries. For developing countries, around 50% of the adult population have no schooling while less than 5% have some higher education. For OECD countries only less than 5% have no schooling and more than 15% have some higher education. Differences are even more striking at the individual country level. Figure 2 shows that there are poor countries with more than 80% of the adult population with no schooling, while rich countries have less than 1%. I take this evidence as indicating that most of the cross-country difference in average years of schooling is due to differences in the distribution of individuals across schooling groups.

3 Economic Environment

The economic environment can be described as follows. There are an infinite number of generations that live for two periods. There is a mass one of agents in each generation and population is constant, each agent gives birth to an offspring at the beginning of the second period of life. Agents are endowed with one unit of time in each period. Generations are organized into dynasties, second-period agents (old or parents) care about the utility of first-period agents (young or children). Preferences for an old agent of generation \( t \) at time \( t \) are given by

\[
U_t = u(c_t) + \delta u(c_{t+1}') + \delta \beta U_{t+1}
\]

where \( c' \) is young agent’s consumption, \( \delta \) is the generation discount factor, and \( \beta \) is the time-period discount factor.

There are two technologies to produce the output good in this economy: Modern and Traditional\(^2\). The feature that I want to capture with these two technologies is that modern technologies are more intensive in the use of services from physical and schooling capital. For simplicity, I take the extreme view that traditional technologies do not require the services of physical and schooling capital as inputs. In particular, the traditional technology is given by

\[
Y^T = F^T(L, N) = A_T L^\alpha T N^{1-\alpha T}
\]

where \( A_T \) is a technology-specific parameter, \( L \) is the input of land services, and \( N \) is input of (raw) labor services of the population working in this sector. The modern technology is given by

\[
Y^M = F^M(K, H) = K^\alpha M (A_M H)^{1-\alpha M}
\]

where \( K \) is the input of aggregate physical capital services, \( H \) is the input of productive labor services (aggregate schooling capital) of the population working in this sector, and \( A_M \) is the technology-specific labor augmenting productivity parameter. As in Lucas (1988), the

\(^2\)Considering these two types of technologies is a simplification of a more general fact that there is an array of technologies with different requirements of skills. Technological progress and adoption are key for the distribution of agents across these technologies and therefore across skill levels.
skill level of an agent is measured by the schooling capital level $h$. In the modern sector, a full time worker with skill $h$ is the productive equivalent of two full time workers with skill $h/2$, or a half time worker with skill $2h$.

The skill level of an agent is determined by the following schooling technology. A young agent has an endowment of "basic" skills (I normalize it to one). If this agent does not spend time in school, the skill level or schooling capital is one. If this agent spends some time in school, the endowment of "basic" skills is completely depreciated or lost $^3$, and the schooling capital level is given by the function $G$, which has three inputs: expenditures in education, $e$, time spent in school, $n$, and schooling capital of old agents or parents, $h^o$. Formally, the schooling technology is given by,

$$h^y = \begin{cases} 
G(e, n, h^o) & \text{if } n > 0 \\
1 & \text{if } n = 0 
\end{cases}$$

where $h^y$ is the schooling capital of a young agent. The schooling capital of an agent, whether the agent invest in school or not, does not depreciate between periods, and therefore the law of motion for this capital can be described by $h' = h^y$. I assume that those agents investing in education spend time in school first and then work the rest of the period as skilled agents.

Old agents make all decisions: consumption of the family, bequests in the form of physical capital, and school investments of young agents (time in school and expenditures in education).

Total output can be divided into consumption, investments in physical capital, and expenditures in education. The law of motion for physical capital is given by,

$$K' = (1 - \delta_k)K + X_k$$

There is only one dimension in which economies differ in this environment. I study two possibilities. In the first version of the model, there are inter-temporal distortions affecting investment decisions in physical capital. For simplicity, I assume that these distortions are represented by taxes to investment in physical capital, $\theta$, and that tax revenues are distributed back to consumers as a lump-sum transfer, $Tr$. I use the relative price of the investment good over the consumption good reported in Restuccia and Urrutia (1996) as a measure of these distortions. In the second version of the model, there are differences in the labor-augmenting productivity parameter in the modern sector $A_M$. I use Hall and Jones (1998) aggregate labor-augmenting productivity calculations as a measure of these differences. In what follows, I only present the model with tax distortions to physical capital investments, but only a small transformation is required for the second version of productivity differences. I report the comparative results between these two alternative versions of the model in section 6.

The problem of an old agent can be defined recursively in the following way. Let $s = (k, l, h, m)$ be the individual state vector at the beginning of the period when old. An old agent in state $s$ has $k$ units of physical capital, $l$ units of land, schooling capital $h$, and school attendance when young $m \in \{0, 1\}$, where $m = 1$ if attended school when young. The $^3$This simply means that basic skills are replaced by new, more advanced skills, in the sense that basic skills are not effectively used in the modern production of goods in this environment.
space of states is defined by $S = K \times H \times L \times \{0,1\}$ and $\mu : S \to [0,1]$ is the distribution of old agents across all possible states. Therefore, $\mu(s)$ represents the mass of old agents in state vector $s$. The dynamic problem for an old agent at the beginning of the period is represented by the following Bellman's equation. Given prices, transfers, and the law of motion for the aggregate state, old agents solve:

$$v(s, \mu) = \max_{\{c,c',h,n,e,k',l',x_k,m'\}} \left\{ u(c) + \delta u(c') + \delta \beta v(s', \mu') \right\}$$  \(1\)

s.t. \(c + c' + e + (1 + \theta)x_k + q(\mu)(l' - l) = y^0 + y^\mu + r_l(\mu)l + r_k(\mu)k + Tr(\mu)\)

$$h^v = \begin{cases} G(e, n, h^o) & \text{if } n > 0 \\ 1 & \text{if } n = 0 \end{cases}$$

$$x_k = k' - (1 - \delta_k)k$$

$$\mu' = \Gamma(\mu)$$

$$m' \in \{0, 1\}$$

$$h' = h^v$$

where

$$y^o = \begin{cases} w_T(\mu) & \text{if } m = 0 \\ w_M(\mu)h & \text{if } m = 1 \end{cases}$$

$$y^\mu = \begin{cases} w_T(\mu) & \text{if } m' = 0 \\ w_M(\mu)h^\mu(1 - n) & \text{if } m' = 1 \end{cases}$$

and $c$ is consumption of the old agent, $c'$ is consumption of the young agent, $e$ is expenditures on education, $q$ is the price of land in terms of the consumption good, $n$ is time young agents spend in school, $h^v$ is the schooling capital of young agents, and $m'$ is the indicator function of school attendance of young agents. $\theta$ is a tax distortion to investments in physical capital, $Tr$ is a lump-sum transfer of receipts from distortion taxes, and $\Gamma(\mu)$ is the law of motion for the aggregate state $\mu$. The income side of the budget constraint is composed of labor income of the old, $y^o$, the return to services of physical capital and land, government transfers, $Tr$, and labor income of young agents, $y^\mu$. Note that I restrict unskilled agents to work in the traditional sector and skilled agents to work in the modern sector. It turns out that for all relevant parameterizations of this model, this restriction is never binding.

At each date, firms in the modern sector choose $K$ and $H$ to maximize profits, taking prices as given. Formally, these firms solve the following static maximization problem:

$$\max_{(K,H)} \left\{ F^M(K, H) - w_MH - r_kK \right\}$$  \(2\)

s.t. \(K, H > 0\)

Firms in the traditional sector, taking prices as given, choose $L$ and $N$, to maximize profits. These firms solve the following problem:

$$\max_{(L,N)} \left\{ F^T(L, N) - w_TN - r_LL \right\}$$  \(3\)
A Recursive Competitive Equilibrium is a set of functions: value function of consumers \( v(s, \mu) \), policy functions of consumers \( g^y(s, \mu), g^x(s, \mu), g^r(s, \mu), g'^y(s, \mu), g'^x(s, \mu), g'^r(s, \mu) \), policy functions of firms \( f^K(\mu), f^H(\mu), f^N(\mu), f^L(\mu) \), price functions \( w_M(\mu), r_k(\mu), r_l(\mu), q(\mu) \), transfer function \( T_r(\mu) \), and a law of motion for the aggregate state \( \Gamma(\mu) \), such that:

(i) Given prices \( w_T(\mu), w_M(\mu), r_k(\mu), r_l(\mu), q(\mu) \), transfer \( T_r(\mu) \), and the law of motion for the aggregate state \( \Gamma(\mu) \); \( v(s, \mu) \) solves the consumer's problem in (1) and generates the optimal policy functions specified above.

(ii) Given prices \( w_T(\mu), w_M(\mu), r_k(\mu), r_l(\mu) \); optimal policy functions \( f^K(\mu), f^H(\mu), f^N(\mu), f^L(\mu) \) solve the firms' problem in (2) and (3).

(iii) Markets Clear: Let any aggregate variable \( X \) be defined as,

\[
X = \int_S g^x(s, \mu) \mu(s) ds
\]

then, the resource constraint is given by,

\[
C + C_y + E + X = F^M(f^K, f^H) + F^T(f^L, f^N)
\]

land market clears,

\[
\int_S g'^y(s, \mu) \mu(s) ds = L
\]

aggregate factor inputs consistent with individual behavior,

\[
\begin{align*}
\int_S l\mu(s) ds &= L \\
\int_S k\mu(s) ds &= K \\
\int_S (1 - m)\mu(s) ds + \int_S (1 - g'^r(s, \mu))\mu(s) ds &= f^N(\mu) \\
\int_S h\mu(s) ds + \int_S g'^r(s, \mu)[1 - g''(s, \mu)]g^h(s, \mu)\mu(s) ds &= f^H(\mu)
\end{align*}
\]

and the government constraint holds.

(iv) Consistency: Individual's policy functions define an operator \( \Phi(\mu) \) that maps current measure \( \mu \) into tomorrow measure \( \mu' \). \( \Phi(\mu) \) is the law of motion for the aggregate state implied by individual behavior. The law of motion for the aggregate state, \( \Gamma(\mu) \), is consistent with individual policy functions if

\[
\Gamma(\mu) = \Phi(\mu)
\]

A Stationary Recursive Competitive Equilibrium is a RCE in which the aggregate state, \( \mu \), is constant over time. Formally, it is a RCE such that \( \mu = \Gamma(\mu) \).
4 Characterization of a Stationary Equilibrium

Factor prices are given from the maximization problem of firms. The wage rate in the modern sector and the rental rate of physical capital services are given by,

\[ r_k(\mu) = \alpha_M A_M^{1-\alpha_M} \left( \frac{K}{H} \right)^{\alpha_M - 1} \]  \hspace{1cm} (4)

\[ w_M(\mu) = (1 - \alpha_M) A_M^{1-\alpha_M} \left( \frac{K}{H} \right)^{\alpha_M} \]  \hspace{1cm} (5)

and the wage rate in the traditional sector and the rental rate of land services are given by,

\[ w_T(\mu) = (1 - \alpha_T) A_T \left( \frac{L}{N} \right)^{\alpha_T} \]  \hspace{1cm} (6)

\[ r_I(\mu) = \alpha_T A_T \left( \frac{L}{N} \right)^{\alpha_T - 1} \]  \hspace{1cm} (7)

I simplify the problem of an old agent in the following two ways. First, I aggregate young and old utility for consumption. Since the allocation decision between consumption of the old and young agents is static, and irrelevant for the purposes of this research, I define aggregate utility of the family for consumption today, \( \tilde{u}(\cdot) \), as:

\[ \tilde{u}(c, c') = u(c) + \delta u(c') \]

where

\[ u(.) = \frac{(.)^{1-\sigma} - 1}{1 - \sigma} \]

The equilibrium decision between consumption of the old and young implies that

\[ c' = \delta^\sigma c \]

which in turn implies

\[ \tilde{u}(\tilde{c}) = \frac{(1 + \delta (1 + \sigma (1 - \sigma)))}{(1 + \delta^\sigma (1 - \sigma))} \tilde{c}^{1-\sigma} - 1 - \delta \]

where \( \tilde{c} = c + c' \) is total consumption of the family.

Second, I aggregate physical capital and land into total assets. Define \( a \) as the total asset position of an old agent at the beginning of the period. The price of a unit of asset \( a \) is normalized to that of the consumption good, and assets are composed of two types of capital, physical capital \( k \) and land \( l \), in the following way:

\[ a = (1 + \theta)k + ql \]

where \( q \) is the price of land in terms of the consumption good. An arbitrage condition on the rental rates of return on these two capitals in stationary equilibrium implies:

\[ r = \frac{r_l}{q} = \frac{r_k}{(1 + \theta)} - \delta_k \]  \hspace{1cm} (8)
where \( r, r_t, \) and \( r_k \) are the rental rates of return on assets, land, and physical capital respectively. Therefore, old agents care about the total asset position \( \alpha \) and not on its composition.

These two transformations give a simpler problem. An old agent in state \( s = (\alpha, h, m) \) solve the following programming problem. To save on notation, the aggregate state \( \mu \) is omitted. Let \( \tilde{\beta} = \delta \beta \) be the effective discount rate.

\[
v(s) = \max_{(\tilde{c}, a', c, e, n, h', m')} \left\{ \tilde{u}(\tilde{c}) + \tilde{\beta} v(s') \right\}
\]

\[
s.t. \quad \tilde{c} + a' - a + e \leq y^o + y^u + ra + Tr
\]

\[
h^u = \begin{cases} G(e, n, h^o) & \text{if } n > 0 \\ 1 & \text{if } n = 0 \end{cases}
\]

where

\[
y^o = \begin{cases} w_T & \text{if } m = 0 \\ w_M h & \text{if } m = 1 \end{cases}
\]

\[
y^u = \begin{cases} w_T & \text{if } m' = 0 \\ w_M h^u (1 - n) & \text{if } m' = 1 \end{cases}
\]

Using the first order condition for the accumulation of assets in a stationary equilibrium, the rate of return on assets, \( r \), is constant over time and given by

\[
r = \frac{1}{\tilde{\beta}} - 1
\]

Note that the rate of return on assets is completely determined by the effective discount rate \( \tilde{\beta} \). From equations (8) and (10), the rate of return on physical capital, \( r_k \), for a given distortion level, \( \theta \), is determined by the effective discount rate. Also, with this value and equation (4), \( K/H \) is determined. From equations (5), (4), (8), and (10), the wage in the modern sector, \( w_M \), is given by

\[
w_M = (1 - \alpha_M) A_M \left\{ \left[ \frac{1}{\tilde{\beta}} - 1 + \delta_k \right] \frac{(1 + \theta)}{\alpha_M} \right\}^{\frac{1}{\alpha_M - 1}}
\]

and therefore is also determined by the effective discount rate for a given distortion level. The fact that the rate of return on assets is constant over time implies that consumption of the family must be constant along a stationary equilibrium.

Assuming an interior solution, the first order conditions with respect to \((e, n, h')\) and the definition of \( h' \) in stationary equilibrium gives.

\[
w_M G_e (1 - n + \tilde{\beta}) + \tilde{\beta} G_h = 1
\]

\[
w_M G_e = \frac{G_n}{h}
\]

\[
h = G
\]
Let $G = B e^c h^\tau n^\gamma$, then in a stationary equilibrium $(n, h, e)$ are given by:

$$n_{se} = \frac{\gamma (1 + \bar{\beta})}{1 + \gamma - \bar{\beta} \tau} \quad (12)$$

$$h_{se} = \left\{ \frac{B (\frac{\xi}{\gamma} w_M) \xi n_{se}^\gamma + \xi}{1 - \frac{1}{\tau}} \right\} \quad (13)$$

$$e_{se} = \frac{\xi}{\gamma} w_M n_{se} h_{se} \quad (14)$$

- **Proposition 1**: In a stationary equilibrium, (i) Time spent in school, $n_{se}$, is constant across economies. In particular, it is independent of distortions, $\theta$. (ii) Expenditures in education, $e_{se}$, and individual's schooling capital, $h_{se}$, are decreasing in distortions, $\theta$.

**Proof**: The result in (i) is a direct consequence of equation (12) and the result in (ii) from equations (13) and (14), and the fact that the wage in the modern sector, $w_M$, is decreasing in distortions.

The intuition for these results is straightforward. In (i), the Cobb-Douglas assumption in the modern technology implies that the impact of distortions on productivity levels over the wage in the modern sector affect proportionally the marginal benefit and the opportunity cost of education. The time spent in school, $n_{se}$, only depends on the elasticity of school time on schooling capital, $\gamma$, the effective discount rate, $\bar{\beta}$, and the elasticity of parent's schooling on child's schooling, $\tau$. The elasticity of expenditures in education on schooling, $\xi$, and the scaling factor $B$ of the schooling technology, do not affect school time for the same reasons described above for distortions. The result in (ii) is a consequence of the complementarity between physical and schooling capital in the modern technology. Agents in highly distorted economies do not invest as much in schooling for the same reasons that they do not invest as much in physical capital. Distortions affect directly the return to physical capital investments, and indirectly the return to educational expenditures through lower wages.

Let $\phi$ be the fraction of old agents that work in the traditional sector. I study economies in stationary equilibrium in which all educated agents work in the modern sector and all uneducated ones in the traditional sector, and therefore $\phi$ also represents the fraction of old agents with no schooling. In a stationary equilibrium, $\phi$ must be constant and it is optimal for an educated parent to have an educated child. There is no intergenerational mobility in a stationary equilibrium in this model. Therefore there must be no agent with incentives to switch its dynasty to a different educational category. Let $W^j_i(s; \phi)$ be the corresponding value function of an old agent in category $i \in \{E, U\}$ with the property that the dynasty stays or moves to category $j \in \{E, U\}$, for each value of $\phi$, where $E$ and $U$ represent the educated and uneducated category respectively. The objective is to find a $\phi$ such that no agent wants to move from the current state. The following are sufficient copditions:

\begin{align*}
(C.1) \quad W_E^E(a, h_{se}, 1; \phi) & \geq W_U^E(a, h_{se}, 1; \phi) \\
(C.2) \quad W_U^U(a, 1, 0; \phi) & \geq W_U^E(a, 1, 0; \phi)
\end{align*}
The intuition for these conditions is straightforward, (C.1) states that an educated old agent prefers to keep the dynasty in the educated category than to switch to the uneducated category, and similarly (C.2) for an uneducated old agent.

The value functions $W_E^E(a, h_{se}, 1; \phi)$ and $W_U^U(a, 1, 0; \phi)$ are straightforward to compute analytically. The decisions of family consumption, asset accumulation, and school investments for these types of agents in stationary equilibrium imply:

$$W_E^E(a, h_{se}, 1; \phi) = \frac{\bar{u}(w_M h_{se} + ra + T r - e)}{1 - \bar{\beta}}$$

$$W_U^U(a, 1, 0; \phi) = \frac{\bar{u}(2w_T + ra + T r)}{1 - \bar{\beta}}$$

(15) (16)

The value functions of switching $W_E^U(a, 1, 0; \phi)$ and $W_E^E(a, h, 1; \phi)$ are more complicated to calculate since there is a process of accumulation or de-accumulation of assets. The value function of switching from the educated category to the uneducated category is defined as:

$$W_U^E(a, h_{se}, 1; \phi) = \max_{\{a^*\}} \left\{ \bar{u}(w_M h_{se} + w_T + (1 + r)a - a' + T r) + \bar{\beta} W_U^U(a', 1, 0; \phi) \right\}$$

In this case, all schooling capital $h$ is lost, and the only decision variable is $a'$. Since $r$ is constant in a stationary equilibrium, the consumption of the family must be constant, and assets are accumulated at once in proportion to the change in relative wage income, given by

$$\bar{a} = \frac{w_M h - w_T}{1 + r} + a$$

Hence,

$$W_U^E(a, h_{se}, 1; \phi) = \frac{\bar{u}(2w_T + r\bar{a} + T r)}{1 - \bar{\beta}}$$

(17)

The value function of switching from the uneducated to the educated category is defined by:

$$W_E^U(a, 1, 0; \phi) = \max_{\{a', h', n, e\}} \left\{ \bar{u}(w_T + w_M h' (1 - n) + (1 + r)a - a' - e + T r) + \bar{\beta} W_E^E(a', h', 1; \phi) \right\}$$

Since schooling capital must be accumulated, along a stationary equilibrium, the path of $h$ can be calculated as:

$$h' = Ch^{1-\xi}$$

(18)

where

$$C = \left( B(\frac{\xi}{\gamma}, w_M)^{\xi + \gamma} \right)^{1/(1-\xi)}$$

There is a period $T$ after the switch, for which $h_T = h_{T-1} + \xi$, where $\xi$ is a very small number (the tolerance parameter) due to the numerical approximation. At date $T$, the asset accumulation must have stopped with an error of a small number proportional to $\xi$,  

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ie, \( a_{\tilde{T}} = a_{\tilde{T}-1} \), by using the same argument of constant streams of consumption. Applying several recursive substitutions \( a_{\tilde{T}} \) is given by (let \( R = \frac{1}{\frac{1}{1+r}} \)),

\[
a_{\tilde{T}} = w_T R + w_M R[(1 - n)h_1 - (2 - n)h_{\tilde{T}}] + w_M R^2[h_1 + (1 - n)h_2 - (2 - n)h_{\tilde{T}}] + w_M R^3[h_2 + (1 - n)h_3 - (2 - n)h_{\tilde{T}}] + ... + w_M R^{\tilde{T}-1}[h_{\tilde{T}-2} + (1 - n)h_{\tilde{T}-1} - (2 - n)h_{\tilde{T}}] + w_M R^{\tilde{T}}[h_{\tilde{T}-1} - h_{\tilde{T}}] + \frac{\xi}{\gamma} w_M n\{(R + R^2 + ... + R^{\tilde{T}-1})(h_{\tilde{T}} - h_{\tilde{T}-1}) + (R + ... + R^{\tilde{T}-2})(h_{\tilde{T}-1} - h_{\tilde{T}-2}) + ... + (R + R^2)(h_3 - h_2) + R(h_2 - h_1)\} + a
\]

or

\[
a_{\tilde{T}} = w_T R + \bar{a} + a
\]

Hence,

\[
W_M^T(a, 1, 0; \phi) = \frac{\hat{u}(w_M h(2 - n) + ra_{\tilde{T}} - e + Tr)}{1 - \beta} = \epsilon
\]

where \( \epsilon \) is a very small number. As \( \tilde{T} \) goes to infinity, \( \epsilon \) goes to 0, and the approximation is exact.

It is interesting to note that each \( W_j \) depends on \( a \) and \( \phi \), but that conditions (C.1) and (C.2) are independent of \( a \), as it can be seen directly in equations (22) and (23) below. The reason is that there are perfect capital markets in this environment, and therefore old agents can borrow against future generations in order to finance investments in education. Hence, each condition depends only on \( \phi \), and in general there can be a continuum of values for this parameter for which these conditions are satisfied.

Define \( \phi \) such that (C.1) is satisfied with equality. Using equations (15), (17), and (6), \( \phi \) is given by

\[
\phi = \frac{1}{2} \left( \frac{w_M h(2 - n - \frac{r}{1+r}) - e}{(2 - \frac{r}{1+r})(1 - \alpha_T)A_T} \right)^{-\frac{1}{\alpha_T}}
\]

For all \( \phi \in [\phi, 1] \), (C.1) is satisfied since a higher \( \phi \) implies a lower wage in the traditional sector, and therefore a higher option value of staying in the educated category.

Define \( \bar{\phi} \) such that (C.2) is satisfied with equality. Using equations (16), (21), (20), and (6), \( \bar{\phi} \) is given by

\[
\bar{\phi} = \frac{1}{2} \left( \frac{w_M h(2 - n) + r\bar{a} - e}{(2 - \frac{r}{1+r})(1 - \alpha_T)\bar{\alpha}_T A_T} \right)^{-\frac{1}{\alpha_T}}
\]

For all \( \phi \in [0, \bar{\phi}] \), (C.2) is satisfied since a lower \( \phi \) implies a higher wage in the traditional sector, and a higher option value of staying in the uneducated category.
• Proposition 2: For each distortion level \( \theta \), any \( \phi \in [\phi, \overline{\phi}] \) is associated with a stationary equilibrium for this economy.

Proof: In a stationary equilibrium, \( \tau \) and \( n \) are determined by parameter values independent of \( \theta \). For each \( \theta \), there is a unique vector \((w_M, h, e)\) in stationary equilibrium. Then \( \phi \) and \( \overline{\phi} \) are determined by equations (22) and (23). Any \( \phi \in [\phi, \overline{\phi}] \) satisfies (C.1) and (C.2), that are sufficient for a stationary equilibrium. Hence, for each \( \theta \), \( \phi \) is an index of a stationary equilibrium from a continuum.

This proposition does not guarantee existence of a stationary equilibrium, the set \([\phi, \overline{\phi}]\) might be empty. For all reasonable parameterizations of the model, there is always a continuum of stationary equilibrium. The intuition for the possibility of a continuum of stationary equilibrium is related entirely to the form of the schooling technology, in particular, to the elasticity of parent's schooling on child's schooling, \( \tau \). I show formally in Proposition 4, that if \( \tau = 0 \) then a stationary equilibrium is unique. The elasticity, \( \tau > 0 \), implies a curvature in the accumulation of schooling capital for any individual, some generations are required in order to approach the stationary equilibrium value of schooling capital from below. The decision of switching for an individual is based on the entire dynamic path. In a stationary equilibrium wage income for an educated worker is fixed, but wage income for an uneducated worker depends on \( \phi \). The wage income distance between these two agents determines the incentives to switch, which are different for educated and uneducated agents. The curvature in the accumulation of schooling implies a lower wage income during the transition from uneducated to educated agents. This difference is what permits different \( \phi \) to be associated with different stationary equilibrium for this economy.

• Proposition 3: In a stationary equilibrium, both bounds on the fraction of old agents working in the traditional sector (or uneducated old workers), \( \phi \) and \( \overline{\phi} \), are increasing in distortions, \( \theta \).

Proof: This is a direct implication of equations (22) and (23), and the fact that, as equation (11) shows, the wage rate in the modern sector is decreasing with distortions.

Some important implications of this proposition are the following. First, in general, economies with higher distortions use the traditional technology more intensively. Since there is a one to one mapping in the model between the fraction of old agents in the traditional sector, \( \phi \), and the fraction of old agents with no schooling, then fewer agents are investing in school. Second, since average years of schooling for a particular economy in stationary equilibrium is given by

\[
AYS = \phi 0 + (1 - \phi)n
\]

economies with higher distortions have lower average years of schooling. The effect of distortions on average years of schooling in the model is only through changes in the distribution, since time spent in school for educated agents is constant across economies (Proposition 1(i)). I argue that this is a reasonable abstraction, and it is related to Observation 3 in Section 2. Across countries, individuals pursuing say Ph.D. programs, spend about the same amount of time in school. Average years of schooling are high in rich countries because more people complete studies of higher degrees. In fact, using the schooling variables from Barro and Lee
(1993) for 1985, almost 80% of the difference in average years of schooling across countries is accounted for by changes in the distribution between individuals with no schooling and some schooling.

- **Proposition 4:** If the elasticity of parent’s schooling on child’s schooling is zero, $\tau = 0$ and a stationary equilibrium exists for this economy, then it is unique.

**Proof:** In this case, $h' = C = h_{se}$ from equation (18) and (13), implying that the accumulation of schooling capital is immediate since it only requires time and resources. Hence, $\ddot{a} = -w_M h R$ from equations (20) and (19). Substituting this in (23) implies that $\ddot{\phi} = \phi$. The assumption of existence guarantees that this value is between 0 and 1.

## 5 Schooling Technology Specification and Calibration

The technology for schooling capital that I consider includes individual’s time, educational expenditures, and parent’s characteristics as inputs. There is an important literature on the relationship between school resources, parent’s characteristics, and outcomes. Altonji and Dunn (1996) use sibling data on wages and school characteristics, and find that school quality indicators have a substantial effect on wages. Card and Krueger (1996) review similar results in the literature. Neil and Johnson (1996) show that both school resources and family background are significant in the determination of student performance using test scores, school quality, and household information from the National Longitudinal Survey of Youth. Lam and Schoeni (1993, 1994) and Heckman and Hotz (1986) find significant effects of parent’s education on children’s income.

I assume the schooling technology is of the following form:

$$G(e, h, n) = Be^\xi n^\gamma h^r$$

where $B$ is a constant and $\gamma, \xi, \text{ and } \tau$ are positive. Haley (1976) and Lucas (1988) consider similar specifications. Bils and Klenow (1996) consider a version of Mincer (1974) schooling technology, of the following form: $Be^\xi h^r \exp(\gamma n)$. Under this specification of the schooling technology, $\hat{\gamma}$ represents the returns to schooling. In my model using this technology, the required $\hat{\gamma}$ to obtain a stationary equilibrium $n_{se}$ consistent with US data is 1.12, which is too high compared with some micro evidence on the returns to schooling (anywhere from 4 to 12% for the US).

Additionally, there are two important issues concerning this specification for the purposes of my model. First, Mincer’s (1974) formulation is a relationship between log wage rates and equilibrium choices for $n$. For this reason, this formulation is not particularly appropriate in models where schooling is an endogenous variable. Second, the Mincer specification of linearity between log wages and schooling implies, in the context of my model, that the stationary equilibrium $n_{se}$ is decreasing in $\hat{\gamma}$, and that returns to schooling, $\hat{\gamma}$, are constant across countries and across education levels, which is inconsistent with the evidence. For example, Psacharopoulos (1994) finds that returns to schooling are lower for primary schooling than for high school and higher education, and lower for rich countries compared to poor ones. Lam and Schoeni (1993) argue that returns to schooling are higher for poor
countries, and that this conclusion is not affected by the inclusion of family background characteristics.

The schooling technology I consider in this paper is consistent with these and other observations. In particular, the relationship between log wages and stationary equilibrium schooling is almost linear for the calibrated version of this technology, in part because equilibrium expenditures in education are also a function of schooling. I run an OLS regression between log wages and equilibrium schooling with a constant in the context of this model (assuming that schooling time varies for exogenous reasons) and find a slope coefficient of 10%, consistent with the empirical literature.

The parameters to calibrate are: $N_p, \alpha_M, \alpha_T, A_M, A_T, B, \gamma, \xi, \tau, \beta, \delta_k, L$, and $\theta$, where $N_p$ is the length of a period in terms of real life years. The result of this calibration exercise is presented in Tables 2 and 3. Each parameter is set to match relevant observations from the data. $N_p = 30$, in order to match a retirement age of 65 (agents are born at age 5). Additionally, agents start paying for their children's education at age 35. The effective depreciation rate of capital $\delta_k = 0.96$, or 10% annually (since there is no technical progress or population growth in the model). The distortion level $\theta = 0$ for the Benchmark US economy. I normalize the size of land, $L = 1$.

There are 9 parameters remaining. For the US economy the fraction of adult population with no schooling is less than 1%. Therefore I assume that total output of the traditional sector is negligible and the income share of labor gives $\alpha_M$, in particular, $(1 - \alpha_M) = 0.65$. Both $\xi = 0.3$ and $\tau = 0.12$ are taken from the microeconomic literature on the returns to schooling. Altonji and Dunn (1996) find significant effects of school inputs on wages. They run regressions of log wages on four different proxies for the quality of school inputs, using siblings data in order to control for fixed effects of family characteristics that are common to siblings. They find an average elasticity of school quality inputs on wages of 0.3. This result is somewhat similar to previous results in the literature using different data approaches, surveyed in Card and Krueger (1996).

Lam and Schoeni (1993) use a large survey of Brazilian households to evaluate the effect of parent's characteristics on schooling choices and wage outcomes for sons. They run regressions of log wages for sons on own schooling, and schooling characteristics of parents. They find a very strong relationship between father's education and the education and earnings of sons: in average, a man with a university educated father has 12 more years and 10 times more earnings than a man with an illiterate father. Controlling for own individual and mother's education, an additional year of father's education increases log earnings in 2%. Mother's education has similar quantitative effects. Therefore, since average years of schooling of parents in this sample is 3, the elasticity of parent's education is 0.12. Lam and Schoeni (1994) report similar findings for this elasticity using US data. This estimate is a lower bound for $\tau$ since parent's $h$ includes more than just years of formal education. Alternative measures of this elasticity come from the intergenerational income mobility literature. Solon (1992) and Zimmerman (1992) report estimates for the elasticity of parent's income on child's income around 0.4. Stokey (1992) offers an excellent survey of this literature and cites estimates between 0.4 and 0.7. Even though there is no intergenerational income mobility in the steady state of my model, these estimates would be more relevant if $h^s$ is better correlated with income than with years of schooling of parents. I use the $\tau = 0.12$ estimate as the benchmark and Table 6 reports the implications of using a higher
estimate.

There are 6 parameters remaining. I apply the following procedure using data for 1985. Step 1: Choose $\beta$ to match a physical capital-output ratio of 2.5 for the US, which gives an annual interest rate of 5.6%. Step 2: Choose $\gamma$ to match an average years of schooling of 11.8 for the US, using the information on the fraction of adult population with no schooling. Step 3: $B$ is simply a scaling factor. The physical capital-output ratio and real per worker GDP determine $h$ using the definition of the modern technology in steady state. Choose $B$ to match this value of $h$. Step 4: For a given $A_M$ and $\alpha_T$, find $A_T$ such that the stationary equilibrium value of $\phi$ for an economy with no distortions matches a level of no schooling population of 0.85% for the US. Step 5: Find $\alpha_T$ such that the stationary equilibrium value of $\phi$ for a highly distorted economy, given the function $A_T(\alpha_T)$, matches the no schooling population for a highly distorted country (around 90% for Benin in my sample of countries), given the value of $A_M$ specified in Step 4. With this choice of $\alpha_T$, total factor productivity in the traditional sector is given by $A_T = A_T(\alpha_T)$. Step 6: Labor-augmenting productivity in the modern sector, $A_M$, is almost a normalization. When stationary equilibrium is unique ($\tau = 0$), then $A_M$ is a complete normalization (only the $A_M/A_T$ ratio matters, but when stationary equilibrium is not unique, $A_M$ determines the distance between $\phi$ and $\bar{\phi}$). Choose $A_M$ so that the value of $\bar{\phi}$ for a non-distorted economy is 2.5% (Ireland in my sample of countries).

These parameter choices are consistent with some other observations. First, the wage gap between an educated old agent and an uneducated one is 2.3 in the model, which is similar to some calculations of the wage gap using standard returns to schooling from the empirical literature. Second, the income share of labor is pretty much constant across economies, consistent with the findings of Gollin (1997). Third, the model produces consistent results in terms of returns to schooling. For the US economy, returns to schooling range from 4 to 12% depending on the data and methodology used. Ashenfelter and Zimmerman (1997) run regressions of log wages on individual’s schooling and other controlling variables, using data on brothers and parents-sons that controls for an important part of parent’s $h$ but not for all $e$ differences. They estimate returns to schooling between 6 to 9%. Under the schooling technology I use in this paper, and assuming that $n$ varies for exogenous reasons, I run regressions of log wages on schooling time in the model. Holding educational expenditures $e$ and parent’s schooling capital $h^o$ constant, the return to schooling (the parameter estimate from the regression) is given approximately by $\frac{2}{n}$, where $\bar{n}$ is the average years of schooling in the sample. Using the numbers of the calibration exercise above $\frac{2}{n} = 4\%$ for the US economy. Holding $h^o$ constant, the return to schooling is given approximately by $\frac{2.5}{n} = 9\%$. This estimate is higher because of the bias introduced for the omission of $e$ differences. Without controlling for $e$ and $h^o$ differences, the return to schooling is given approximately by $\frac{2.5}{n} = 11\%$. Therefore, the parameter choices of the schooling technology imply estimates of returns to schooling in the model consistent with the empirical literature.
6 Results

6.1 The "Amplifier Effect"

The model generates statistics for artificial economies that can be systematically compared with the data and other models. Let me first define the Benchmark economy that I use to compare the results of my model. The Benchmark economy is a standard physical and schooling capital model in which there is only one technology to produce the output-good. Time can be devoted to schooling and schooling capital is accumulated following the schooling technology described in the previous section. Using the result of Proposition 1(i), that the time devoted to schooling is constant across economies, relative income in this environment is given by the relative differences in physical capital accumulation only. In particular, for a physical capital income share of $\alpha = 0.35$, if the factor difference in the relative price of investment goods (distortions) between two economies is 4, then the Benchmark model generates an income disparity of 2.1.

To evaluate the performance in terms of income disparity between my model and the Benchmark, I compute the ratio of the relative incomes between the two models. I call this ratio the "Amplifier Effect", since it measures how much more income disparity the technology adoption and schooling mechanism of my model generates relative to the Benchmark model, for any given set of policies. For the same level of the relative price of investment goods of 4 between two economies, my model implies an income disparity of 6.9, and therefore the "Amplifier Effect" is 3.3. Table 4 and Figure ?? illustrate that the amplifier effect is not linear with respect to the level of distortions, but I argue that a range of relative distortions of 4 is reasonable.

Table 5 illustrates the relative importance of each of the features of the model in accounting for the amplifier effect. The table is divided in four quadrants. The first column "No Technology Adoption" represents the model in which only the modern technology is available to produce the output-good. The second column represents the model with both the modern and the traditional technologies, and therefore the adoption of the modern technology is a feature of this version of the model. The first row "No Schooling Quality" is the model in which the schooling technology is such that educational expenditures and parent's schooling do not affect children's schooling capital. Therefore, it is a version of the model in which there are no schooling quality differences, only time spent in school matters, as in Lucas (1988), but that is by Proposition 1(i), constant across economies. The second row represents the model where schooling quality variables matter. In all cases the factor difference in the relative distortions is 4.

The first quadrant in Table 5 represents the Benchmark version of the model, as described above. Income disparity in this case is 2.1. The second quadrant represents the case in which the technology adoption feature is added to the Benchmark model. In this version, relative income differences are due to physical capital accumulation differences and to the intensity in which the most efficient technology is used. Highly distorted economies have a low physical capital stock and use the modern technology less intensively. In particular, the income disparity implied by this model is 3.05, which is around 50% higher than the disparity in the Benchmark economy. The amplifier effect of the simple technology adoption feature studied here is relatively small, consistent with the findings of other models of
technology adoption in the literature. The third quadrant represents the case in which the schooling quality feature is added to the Benchmark model. In this version, since only the modern technology is available, all agents spend time in school, but their schooling capital differs across countries. This is because, in highly distorted economies, agents invest less in schooling for the same reasons that they invest less in physical capital. Therefore, relative incomes differ due to physical capital accumulation and quality of education differences. The income disparity implied by this model is 3.1, around 50% higher than the disparity in the Benchmark model. This is consistent with the results of previous research in which schooling quality by itself is not enough to generate big differences in income across economies.

The fourth quadrant of Table 5 represents the model with both, technology adoption and schooling features together. The amplifier effect is much bigger. Income disparity is 3.3 times higher in this version compared to the Benchmark model. Economies with low distortions not only have a high physical capital stock, but also a low fraction of agents working in a less efficient technology, and a high fraction of agents spending time in school, of higher quality. It is the interaction of the technology adoption and schooling quality features of the model that generates an important amplifier effect of policies on income disparity.

Table 6 reports some sensitivity analysis of changes in the parameters of the schooling technology. It shows that the amplifier effect remains important even for very conservative values of these parameters. Considering values for \( \tau \) similar to reported estimates in Solon (1992) and Zimmerman (1992) can bring the amplifier effect close to 6.

Table 7 reports some other interesting results. First, an educated worker in a low distortion economy earns 3.1 times more than an educated worker in a highly distorted economy (note that this is the same number in the third quadrant of Table 5). The earnings disparity is accounted for by a factor wage difference in the modern sector of 2.1 (higher capital-output ratio), and a factor difference in individual schooling capital of 1.5 (higher schooling quality). Second, income disparity in the modern sector is substantially higher than the overall disparity, which indicates that the fraction of the traditional sector in total output is very high in poor economies. Some of the traditional activities can be identified as "informal" in most poor countries, which means that some of this output might not be properly measured in national income accounts. Blades (1974) reports that unmeasured traditional output can be 40% or more of measured output in poor countries. Young (1995) reports substantial changes in labor participation rates for the East Asian growth miracles. For example, the participation rate in Singapore increased form 27% to 51% from 1966 to 1990. These exceptional changes in labor participation rates must be associated with a reallocation of labor, from traditional (informal) activities to more modern techniques of production. As a very simple experiment, I calculate income disparity for the case in which some constant fraction of the traditional output is not measured in every economy. Table 8 reports the results of these experiments. For example, if 30% of traditional output is not measured in every economy, income disparity is 9.3 and the "amplifier effect" is 4.4. The ratio of unmeasured to measured output is 36% for the poorest economy. If 50% of the traditional output is not measured, then income disparity is 12 (an amplifier effect of almost 6!) For the poorest economy, the ratio of unmeasured to measured output is 70%.

The results of the model are broadly consistent with the cross-section pattern of the schooling data. Figure 3 compares the no schooling population and distortions for the
data and the model. The dots represent the data and the lines the model. The vertical distance between the two lines represents the continuum of stationary equilibrium for each distortion level. It is interesting to note that at each level of distortions, the model generally generates lower no schooling populations compared with the data, and this is especially true for relatively poor countries. This observation is related to the fact that in the model there are perfect capital markets for investments in schooling, parents have the ability to borrow against the income of future generations. In poor countries, even though agents have incentives to invest in schooling, it might not be financially possible. Figure 4 compares the no schooling population and relative income between the model and the data. In the model, as it is in the data, rich economies have very low no schooling populations. Another way to look at this is in Figure 5 that compares average years of schooling and relative income between the model and the data. It shows that in terms of schooling, rich countries are poorer economies in the model and poor countries are richer economies in the model. Figure 6 compares distortions and relative income between the model and the data. The shape of this relationship is captured well by the model, but clearly the model generates less income disparity than the one observed in the data. I emphasize that it is not the intention of this model to account for all the disparity in the data.

6.2 Productivity vs. Distortion Differences

I evaluate the implications of the model under a different assumption regarding policy differences across countries. Suppose that instead of distortions, economies differ in the labor augmenting productivity parameter in the modern technology. I use a standard calculation of labor-augmenting productivity reported by Hall and Jones (1998) as a measure of the differences in the modern technology, and assume that total factor productivity in the traditional sector is equal across economies. The range of total factor productivity differences is less than 6 in the data, while the factor difference in distortions is about 4. In order to make the results of this experiment comparable with the previous results using distortions, I set the range of productivity in the model to 4 (therefore with a capital share of 1/3, the range of labor-augmenting productivity is 8.4). For simplicity, I compute the results of the model for $\tau = 0$.

The income disparity implied by the productivity model is 20 (compared to 5.3 from the model with distortions and $\tau = 0$, see Table 6). The intuition for why disparity is higher in the productivity model is that differences in $A_M$ act as a tax to investments for which revenues are lost. However, the "amplifier effect" between these two versions is about the same, 2.5, since 20 must be compared with a disparity of 8.4 in the Benchmark model with productivity differences. Therefore, I conclude that the "amplifier effect" result of the

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4This is a reasonable approach to think about differences across countries. There is enough empirical evidence supporting the view that better technologies are being adopted less frequently and used less efficiently in poor countries. However, there are two main reasons for why I favor the story of distortions as opposed to the productivity story as laid out in this section. First, I believe the distortion story and its measure is more directly connected to policy actions for individual countries, like obstacles to production, barriers to trade and technology adoption, among others. Productivity differences can be the result of distortions in an appropriate model. Second, the model with productivity differences in steady state generates the counterfactual implication that capital/output ratios are constant across economies. Measured at international prices, capital/output ratios vary systematically with development.
technology adoption and schooling mechanism is robust to different interpretations of policy differences across countries. Figures 7, 8, and 9 show that this version is also consistent with the schooling differences across countries.

6.3 Policy Experiment: A Subsidy to Education

I evaluate the effects of a subsidy policy to education. Subsidies to education are common practice in developing countries, frequently motivated with the idea that raising the average level of education of the population would increase the average income of the economy. The experiment consists on the following: a highly distorted economy establishes a subsidy to those individuals spending time in school. The size of the subsidy is one required to achieve a steady state level of no schooling population equal to the level of an economy with no distortions. To evaluate the effects of the subsidy alone, I assume that the subsidy is financed through a lump-sum tax.

Table 9 reports the results of this experiment and is a comparison of two steady states, with and without the subsidy policy, for an economy with the highest distortions. The magnitudes in the table are intended to represent a gross measure of the mechanics at work in order to promote a discussion. For a highly distorted economy, the subsidy necessary to achieve a level of no schooling population of an economy without distortions is 54% of the new steady state output with the subsidy. Yet, the subsidy policy generates a new steady state output that is 3.1 times lower to the one that would be achieved if, as an alternative policy, distortions were eliminated completely.

In the context of my model where education is not a barrier to riches, this experiment illustrates the following. In highly distorted economies, agents do not invest (time and resources) in education for the same reasons that agents invest less in physical capital. Subsidies to education do not eliminate the negative incentives that distortions impose over capital investments. Subsidies to education can be justified in the context of an environment of imperfections in the capital market to finance schooling investments. In poor countries, economic policy efforts should concentrate on eliminating distortions to capital accumulation, which by itself will promote a reduction of the no schooling population. Subsidies to education might be applied later to resolve difficulties in financing these schooling investments. The motivation for an environment in which education is not a barrier to riches is based on the observation that investors would hire educated workers to adopt and operate new technologies elsewhere if the incentives are appropriate, which in turn would motivate individuals to invest in education. In poor countries, these incentives are not in place.

7 Conclusions

Neoclassical growth models require large productivity/distortion differences across countries to produce the observed disparities in the wealth of nations. In this paper I develop an otherwise very standard neoclassical model with technology adoption and schooling decisions, and show that in this environment the required productivity/distortion differences are much smaller. The schooling and technology adoption features of the model amplify the effects of productivity/distortion differences on income disparity. In particular, for a reasonable
parameterization, the model generates 3 times more income disparity than a standard model. Moreover, I find that it is the interaction between the technology adoption and schooling features of the model, and not each in isolation, that accounts for most of the amplifier effect.

I show that the model is consistent with the observed patterns of the schooling differences across countries. Standard neoclassical models with schooling have the implication that schooling levels are constant across economies, since wage differences affect in the same proportion the marginal benefit and the opportunity cost of schooling. In my model, average levels of schooling do vary across economies since education is more useful in modern technologies and rich economies use these technologies more intensively.

There are some interesting implications for future research. First, a model with capital market imperfections to finance school investments would be relevant to account for some of the disparity in the observed patterns of the no schooling population across countries, and would make the analysis of a subsidy policy to education more interesting. Second, my model studies the cross-section implications of the schooling data only, but there are other relevant features the data that are particularly interesting. For example, the distribution of schooling has been shifting to the right over time in the last 30 years or more, for both poor and rich countries. It would be interesting to evaluate the role of technical progress in accounting for these changes in the context of a model of schooling and technology adoption.
Table 1: Distribution of Adult Population Across Schooling Groups: 1985

<table>
<thead>
<tr>
<th>Region</th>
<th>No Schooling</th>
<th>Some Schooling</th>
<th>AYS</th>
</tr>
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<tbody>
<tr>
<td>Developing (73 Countries)</td>
<td>49.7</td>
<td>50.3</td>
<td>3.6</td>
</tr>
<tr>
<td>OECD (23 Countries)</td>
<td>3.3</td>
<td>96.7</td>
<td>8.9</td>
</tr>
<tr>
<td>Middle East (12 Countries)</td>
<td>52.8</td>
<td>47.2</td>
<td>3.5</td>
</tr>
<tr>
<td>Latin America (23 Countries)</td>
<td>22.4</td>
<td>77.6</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Source: Barro and Lee (1993), Table 6, pages 383-4. Regional averages are weighted by each country's population aged 25 and over.
Table 2: Baseline Parameter Values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_p$</td>
<td>30</td>
</tr>
<tr>
<td>$\theta$</td>
<td>0</td>
</tr>
<tr>
<td>$\delta_k$</td>
<td>0.96</td>
</tr>
<tr>
<td>$\alpha_M$</td>
<td>0.35</td>
</tr>
<tr>
<td>$L$</td>
<td>1</td>
</tr>
<tr>
<td>$\bar{\beta}$</td>
<td>0.24</td>
</tr>
<tr>
<td>$A_T$</td>
<td>2.4</td>
</tr>
<tr>
<td>$A_M$</td>
<td>7</td>
</tr>
<tr>
<td>$\alpha_T$</td>
<td>0.30</td>
</tr>
</tbody>
</table>
Table 3: Parameter Values of Schooling Technology: $G(e, n, h) = Be^{\xi h^\tau n^\gamma}$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\xi$</td>
<td>0.3</td>
</tr>
<tr>
<td>$\tau$</td>
<td>0.12</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0.46</td>
</tr>
<tr>
<td>$B$</td>
<td>8.2</td>
</tr>
</tbody>
</table>
Table 4: Relative Income and Distortions: A Comparative View

<table>
<thead>
<tr>
<th>Policy $(1 + \theta)$ Model</th>
<th>1.5</th>
<th>3.0</th>
<th>4.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Benchmark $\alpha = 0.35$</td>
<td>1.2</td>
<td>1.8</td>
<td>2.1</td>
</tr>
<tr>
<td>(2) Technology-Schooling Ratio $(2)/(1)$</td>
<td>1.5</td>
<td>3.3</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td>1.3</td>
<td>1.8</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Note: Benchmark is a standard physical and schooling capital model with distortions to physical capital investments only, a physical capital’s income share of $\alpha = 0.35$, and a technology for schooling capital as described above. In steady state and given the result in Proposition 1(i), relative incomes are given by $\frac{y_i}{y_j} = \left(\frac{(1+\theta_i)}{(1+\theta_j)}\right)^{\frac{\alpha-1}{\alpha}}$. 
Table 5: Income Disparity and the "Amplifier Effect"

<table>
<thead>
<tr>
<th></th>
<th>No Technology Adoption</th>
<th>Technology Adoption</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Schooling Quality</td>
<td>2.1</td>
<td>3.05 (1.45)</td>
</tr>
<tr>
<td>$\xi = \tau = 0$</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Schooling Quality</td>
<td>3.10</td>
<td>6.9 (3.3)</td>
</tr>
<tr>
<td>$\xi = 0.3, \tau = 0.12$</td>
<td>(1.47)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Income Disparity is the ratio of total output of an economy with $\theta = 0$ over an economy with $\theta = 3$. The "amplifier effect" (in parenthesis) is the ratio of the Income Disparity of each case over the Benchmark Model. No Technology Adoption refers to the model without the traditional technology, and Technology Adoption refers to the adoption of the modern technology.
Table 6: Sensitivity Analysis on Income Disparity (Amplifier Effect)

<table>
<thead>
<tr>
<th></th>
<th>$\xi = 0$</th>
<th>$\xi = 0.1$</th>
<th>$\xi = 0.3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\tau = 0$</td>
<td>3.1 (1.5)</td>
<td>3.6 (1.7)</td>
<td>5.3 (2.5)</td>
</tr>
<tr>
<td>$\tau = 0.12$</td>
<td>3.4 (1.6)</td>
<td>4.0 (1.9)</td>
<td>6.9 (3.3)</td>
</tr>
<tr>
<td>$\tau = 0.4$</td>
<td>4.8 (2.3)</td>
<td>5.6 (2.7)</td>
<td>12.2 (5.8)</td>
</tr>
</tbody>
</table>

Note: For each pair ($\xi, \tau$) I re-run the calibration algorithm described in the calibration section in order for the model to be consistent with the key observations described there.
Table 7: Some Additional Results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>$w_M h$</td>
<td>3.1</td>
</tr>
<tr>
<td>$w_M$</td>
<td>2.1</td>
</tr>
<tr>
<td>$h$</td>
<td>1.5</td>
</tr>
<tr>
<td>$e$</td>
<td>3.1</td>
</tr>
<tr>
<td>$Y^M$</td>
<td>55</td>
</tr>
<tr>
<td>$Y$</td>
<td>6.9</td>
</tr>
</tbody>
</table>

Note: The Range refers to the ratio of an economy with $\theta = 0$ and an economy with $\theta = 3$ for each particular variable.
Table 8: Unmeasured Traditional Output and Income Disparity

<table>
<thead>
<tr>
<th>Fraction of Trad. Output Unmeasured</th>
<th>$\psi = 0$</th>
<th>$\psi = 0.3$</th>
<th>$\psi = 0.5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income Disparity</td>
<td>6.9</td>
<td>9.3</td>
<td>12.2</td>
</tr>
<tr>
<td>&quot;Amplifier Effect&quot;</td>
<td>3.3</td>
<td>4.4</td>
<td>5.8</td>
</tr>
<tr>
<td>Unmeasured/Measured Output (%)</td>
<td>0</td>
<td>36</td>
<td>70</td>
</tr>
</tbody>
</table>
Table 9: Subsidy to Education: Steady State Analysis

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Subsidy Over New S.S Output with Subsidy</td>
<td>54%</td>
</tr>
<tr>
<td>S.S Output ($\theta = 0$) Over New S.S Output with Subsidy</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Note: The Experiment is to implement a subsidy to all agents going to school in a highly distorted economy ($\theta = 3$). The amount of the subsidy is chosen so that the economy reaches the steady state level of the fraction of no schooling population of an economy without distortions. The subsidy is financed through a lump sum tax.
Figure 1: Labor Augmenting Productivity and Years of Schooling
Figure 2: No Schooling Population and Relative Incomes
Figure 3: Distortions and the "Amplifier Effect"
Figure 4: No Schooling Population and Distortions
Figure 5: No Schooling Population and Relative Incomes
Figure 6: Average Years of Schooling and Relative Incomes
Figure 7: Distortions and Relative Incomes
Figure 8: No Schooling Population and Labor Augmenting Productivity
Figure 9: No Schooling Population and Relative Incomes
Figure 10: Labor Augmenting Productivity and Relative Incomes
References


